TECHNICAL NOTES.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 85.

AIR FORCE AND THREE MOMENTS FOR F-5-L SEAPLANE

By the Aeronautics Staff,
Construction Department, Navy Yard,
Washington, D. C.

Prepared under the direction of the
Bureau of Construction and Repair.

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Introduction.- A model of the F-5-L seaplane was made, verified, and tested at 40 miles an hour in the 8' x 8' tunnel for lift and drag, also for pitching, yawing and rolling moments. Subsequently, the yawing moment test was repeated with a modified fin. The results are reported without VL scale correction.

Model.- Figures 1, 12 and 13 give the general appearance and chief dimensions of the model. For subsequent investigation of yawing moments on the original model, it was found desirable to replace the fin of the tail unit by one of approximately 50% greater area and with the rudder-balancing surface omitted. The altered fin is shown by dotted lines in Figures 1 and 12.

Apparatus.- The lift and drag were measured as usual on the Eiffel balance; the pitching and yawing moments on the torsion balance; the rolling moments on a special apparatus improvised for the purpose as shown in Figures 2 and 14. In the latter device, the model is supported from the shank of the torsion balance by means of an emery knife edge which permits it to roll through very small angles without material resistance. The knife edge is parallel to the assumed thrust line and passes through a

* This report is a slightly revised form of the unpublished Report No. 118, Construction Department, Navy Yard, Washington, D. C.

point representing the center of gravity of the seaplane. The moment is measured by means of a small double-platform scale from which a fine steel wire is run downwardly through the ceiling of the wind tunnel, and secured to one wing of the model, continuing to a point near the floor of the tunnel, where it is attached to a shielded weight which keeps it taut. During the test, the rolling displacements of the model were just large enough to permit of reading the indications of the platform balance.

Pitching Moments.- Figure 12 gives the line of resultant air force on the model with elevator neutral; Table I and Figure 3 give, with elevator neutral, 10° up and 10° down, the pitching moments about the transverse centroidal axis, shown in Figure 12. Both figures and the table show that the seaplane with neutral elevator balances at 9° angle of attack about the center of gravity, and, for angles between 0° and 13°, possesses sufficient inherent stability, though unstable above 13°. The diagram at the bottom of Figure 12 shows the center of pressure travel on a plane through the center of gravity parallel to the thrust line.

Figure 3 shows that, for the full scale seaplane, pivoted about its transverse centroidal axis at 40 miles an hour, the shift of the center pressure is nearly one inch per degree change of elevator. The same is indicated by the moment diagram taken together with the lift diagram. Figure 3 furthermore shows that at 9° angle of attack the change of pitching moment for 1° change of angle of attack of the seaplane is 570 pound-feet, and for 1°

angle of elevator is 340 pound-feet. This latter moment remains nearly constant through the usual angles of flight, whereas the moment for change of angle of attack of the seaplane varies considerably.

Yawing Moments with original fin.- Figures 4 and 5 and Tables II and III present the yawing moments; first with the hull neutral and rudder turned; then with the hull yawed and the rudder neutral to it. Under both conditions, the seaplane possesses fair directional qualities at all settings from zero to 20°, positive and negative. Figure 4 indicates that the moment on the rudder is almost exactly proportional to the angle of attack of the rudder.

Yawing Moments with modified fin.- Figures 10 and 11 and Tables II and III show, for increased fin surface, the yawing moments with hull neutral and rudder turned, and for hull yawed and rudder neutral to it. This enlarged fin improves the directional quality for the same rudder moment. The moments about the hinge of the rudder are increased by the removal of the balancing surface, but as these moments are small for usual angles of rudder movement, it appears more desirable to use this area as a part of the fixed fin for directional stabilizing.

The moment for both the original and the modified rudder is sufficient, though not ample, to steer the seaplane on a straight level course with one engine stopped and the other maintaining a flight speed of 67 miles an hour. For at this speed the thrust of the one propeller is 1700 pounds, which gives a yawing moment of 10,200 pound-feet, or that of the rudder at about 20° angle of attack.

Rolling Moments.- Figures 6 and 7 give the rolling moments on the seaplane: first, with the hull axis parallel to the wind and the rudder set at various angles of attack; then with the ailerons neutral and the hull yawed through various angles. These show that with neutral ailerons the rolling moment increases uniformly with yaw from 0° to 20°; also that without yaw it increases continuously with aileron turning from 0° to 20°.

Lift and Drag.- Figure 8 and Tables I and IV, giving the lift, drag and lift/drag, disclose characteristics resembling those for the R.A.F.6 aerofoil. The lift reaches its maximum at about 16° angle of attack. The maximum lift/drag is 8.1 at 9° angle of attack and is not well sustained. The rapid decline in the lift/drag at 16° is due almost entirely to the rapid increase of drag. This value of the maximum lift/drag is not great considering the large aspect ratio. It may be recalled that the Burgess seaplane scout and Curtis HA seaplane had lift/drag ratios respectively equal to 8.7 and 8.1, though the aspect ratio was less than for the present model. The T·B seaplane with an aspect ratio of about 7 discloses a maximum lift/drag ratio of 9.4. In none of these, however, were the models, in their minor details of structure, geometrically similar to the full scale seaplane.

Performance. - Figure 9 shows that the seaplane weighing 13,500 pounds can be sustained at slightly over 55 miles per hour and with 800 horsepower actuating propellers of 75% efficiency, can attain a speed of 96 miles per hour. Owing, however, to the rapid decrease of lift at the higher angles of attack, it would seem best not to navigate at speeds much below 60 miles per hour. In standard air the seaplane should be able to climb at the rate of 185 feet per minute at a speed of 65 miles an hour, and 375 feet per minute at 85 miles an hour.

Table I.

Model

F 5 L seaplane
V = 40 mi/hr.
$V^2 \frac{\rho}{2} = q = 4.1$ lbs/sq.ft.
S = 2.42 ft.
S_q = 9.9 lbs.
Max. span = 4.323 ft.
Scale of model, 1:24
Area of elevators, 0.096 sq.ft.
Span of elevators, .8125 ft.

Angle of Attack	Lift in pounds			Drag in pounds			Pitching moment in lbs.in.		
	Elevator			Elevator			Elevator		
	10° up	0°	10° down	10° up	0°	10° down	10° up	0°	10° down
- 6	-3.605	-3.289	-3.017	1.208	1.205	1.147	6.200	2.171	- .807
- 3	-1.144	-0.669	-0.347	0.902	0.862	0.854	5.925	2.188	- .748
- 1	+0.712	1.068	1.380	0.779	0.742	0.722	---	---	---
0.	1.525	1.897	2.233	0.735	0.707	0.698	5.653	2.283	- .525
1	2.377	2.755	3.076	0.707	0.690	0.696	---	---	---
2	3.188	3.570	3.898	0.707	0.694	0.712	5.548	2.290	- .793
3	3.970	4.355	4.730	0.728	0.717	0.730	---	---	---
4	4.750	5.125	5.470	0.764	0.754	0.792	5.050	1.914	-1.214
6	6.275	6.665	6.983	0.866	0.870	0.909	4.690	1.370	-1.619
8	7.750	8.150	8.510	1.004	1.015	1.063	3.671	.329	-2.573
10	9.220	9.582	9.937	1.175	1.187	1.240	2.134	-.580	-3.503
12	10.520	10.850	11.195	1.377	1.397	1.445	.759	-1.641	-3.835
14	11.550	11.855	12.215	1.650	1.694	1.748	.817	-1.916	-4.812
16	12.050	12.375	12.730	2.214	2.322	2.411	2.204	- .378	-4.360

Full size.

F 5 L seaplane
V = 40 mi/hr.
$V^2 \frac{\rho}{2} = q = 41$ lbs/sq.ft.
S = 1394 sq.ft.
S_q = 5715.4 lbs.
Max. span = 103' 9¼"
Scale - full size
Area of elevators, 56 sq.ft.
Span of elevators, 19' 6".

Angle of Attack	Lift 10° up	Lift 0°	Lift 10° down	Drag 10° up	Drag 0°	Drag 10° down	Pitching moment 10° up	Pitching moment 0°	Pitching moment 10° down
- 6	-2076.0	-1895.0	-1737.5	696.0	694.5	661.0	7143	2500	- 930
- 3	- 659.0	- 385.0	- 200.0	519.2	496.5	492.0	6825	2520	- 862
- 1	410.0	615.0	795.0	448.5	426.4	415.8	---	---	---
0	878/5	1093.0	1286.5	423.2	407.3	402.0	6510	2630	- 605
1	1369.5	1587.0	1771.0	407.3	397.5	400.9	---	---	--
2	1835.0	2056.5	2245.0	407.3	399.7	410.0	6393	2638	- 914
3	2287.0	2508.0	2724.5	419.2	413.0	420.5	---	---	---
4	2736.0	2952.0	3150.0	440.0	434.2	456.1	5820	2204	-1399
6	3615.0	3838.0	4022.0	498.8	501.0	523.5	5405	1578	-1865
8	4465.0	4695.0	4900.0	578.0	584.5	606.5	4230	379	-2965
10	5310.0	5520.0	5724.0	677.0	686.0	714.2	2460	- 668	-4035
12	6060.0	6250.0	6445.0	793.5	805.0	833.0	875	-1890	-4420
14	6655.0	6830.0	7040.0	951.0	976.0	1006.5	941	-2203	-5545
16	6940.0	7130.0	7334.0	1275.0	1337.5	1389.0	2540	- 435	-5025

Table II.

	Angle of respective control surface	Model pounds-inches: Yawing moment, Original fin surface	Yawing moment, Revised fin surface	Rolling moment, Angle of yaw 0°	Rolling moment, Angle of aileron 0°
F 5 L seaplane V = 40 mi/hr. q = 4.1 lbs/sq.ft. Scale of model 1 : 24 Axis of yawing normal to thrust line, 34% of chord length aft of leading edge.	0°	+ .09	+ .16	1.12	1.10
	5°	- .65	- .58	9.22	3.81
	10°	-1.39	-1.29	18.19	6.37
	15°	-2.12	-2.06	25.32	8.72
	20°	-2.89	-2.85	29.88	11.31
		Full size pounds-feet			
F 5 L seaplane V = 40 mi/hr. q = 4.1 lbs/sq.ft. Scale : full size Axis of yaw moment normal to thrust line, 34% of chord length aft of leading edge.	0°	+ 107	+ 184	1290	1268
	5°	- 742	- 667	10620	4380
	10°	-1595	-1492	20950	7340
	15°	-3436	-3382	29180	10040
	20°	-3324	-3392	34420	13040

Table III.

F 5 L seaplane

V = 40 mi/hr.

q = 4.1 lbs/sq.ft.

Scale of model

1 : 24

Area of rudder

Rudder neutral to

axis of hull.

Angle of yaw	Model pounds-inches Yawing moment Original fin surface	Revised fin surface
20°	- 3.40	- 4.27
18°	- 2.92	- 3.54
16°	- 2.46	- 2.93
14°	- 2.03	- 2.44
12°	- 1.63	- 1.98
10°	- 1.32	- 1.56
8°	- 1.00	- 1.13
6°	- 0.69	- .68
4°	- 0.41	- .40
2°	- 0.14	- .07
0°	+ 0.09	+ .16
-2°	0.33	.44
-4°	0.60	.79
-6°	0.88	1.07
-8°	1.20	1.47
-10°	1.52	1.83
-12°	1.89	2.38
-14°	2.28	2.92
-16°	2.70	3.39
-18°	3.15	4.03
-20°	3.60	4.58

F 5 L seaplane

V = 40 mi/hr.

q = 4.1 lbs/sq.ft.

Scale : full size

Area of rudder
33 sq.ft.

Rudder neutral to

axis of hull.

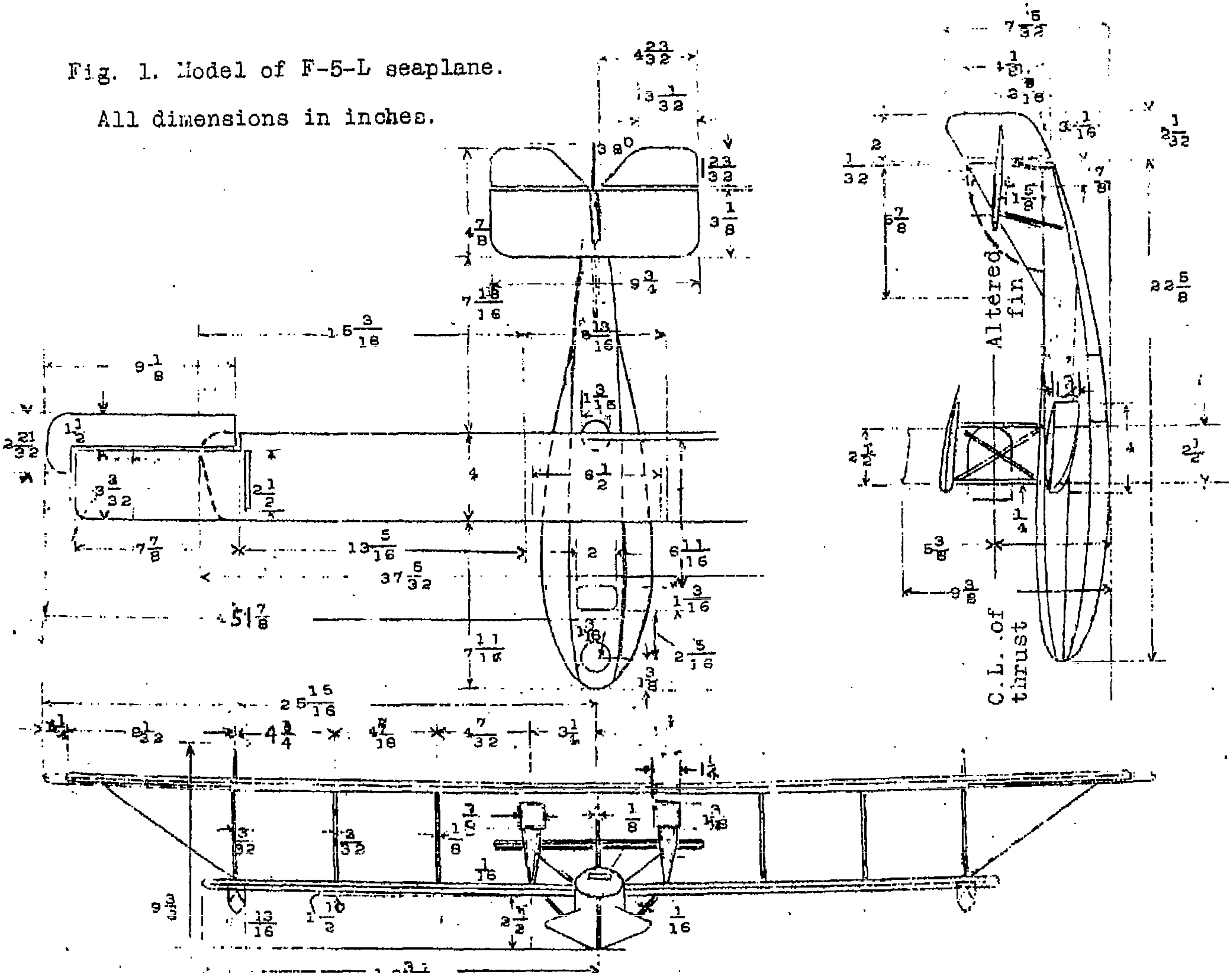
	Full size pounds-feet	
20	-3918	-4920
18	-3363	-4080
16	-2834	-3380
14	-2339	-2810
12	-1878	-2280
10	-1521	-1800
8	-1152	-1302
6	-0795	- 782
4	-0476	- 465
2	-0158	- 85
0	+0107	+ 184
-2	0380	507
-4	0692	908
-6	1014	1233
-8	1382	1695
-10	1752	2110
-12	2188	2740
-14	2627	3364
-16	3111	3910
-18	3628	4645
-20	4147	5280

Table IV.

	Angle	Lift/Drag on model in lbs. — Elevator 10° up	Elevator 0°	Elevator 10° down
		Model		
F 5 L seaplane	-6	-2.984	-2.729	-2.63
V = 40 mi/hr.	-3	-1.268	- .078	- .406
Scale - 1:24	-1	.9139	1.439	1.911
	0	2.075	2.683	3.20
	1	3.362	3.992	4.42
	2	4.509	5.144	5.475
	3	5.453	6.074	6.479
	4	6.217	6.797	6.907
	6	7.246	7.661	7.682
	8	7.719	8.03	8.006
	10	7.847	8.072	8.014
	12	7.639	7.766	7.747
	14	7.000	6.998	6.988
	16	5.442	5.329	5.28
		Full size		
F 5 L seaplane	- 6	-2.982	-2.730	-2.630
V = 40 mi/hr.	- 3	-1.268	-0.776	-0.406
Scale: full size	- 1	+0.914	+1.439	+1.911
	0	2.075	2.685	3.200
	1	3.363	3.992	4.420
	2	4.510	5.145	5.475
	3	5.455	6.075	6.480
	4	6.220	6.800	6.915
	6	7.245	7.660	7.682
	8	7.725	8.030	8.005
	10	7.845	8.070	8.010
	12	7.640	7.718	7.745
	14	7.000	7.000	6.990
	16	5.442	5.570	5.220

Fig. 1. Model of F-5-L seaplane.

All dimensions in inches.



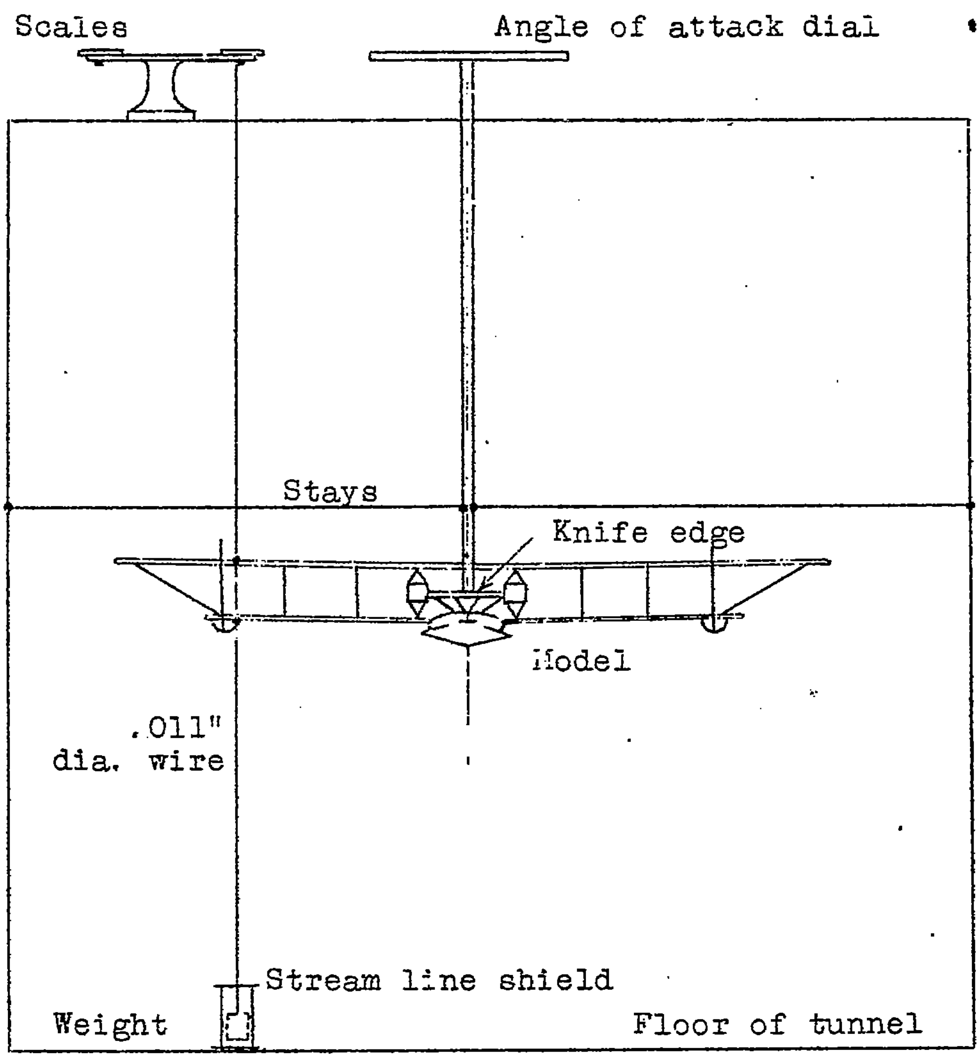
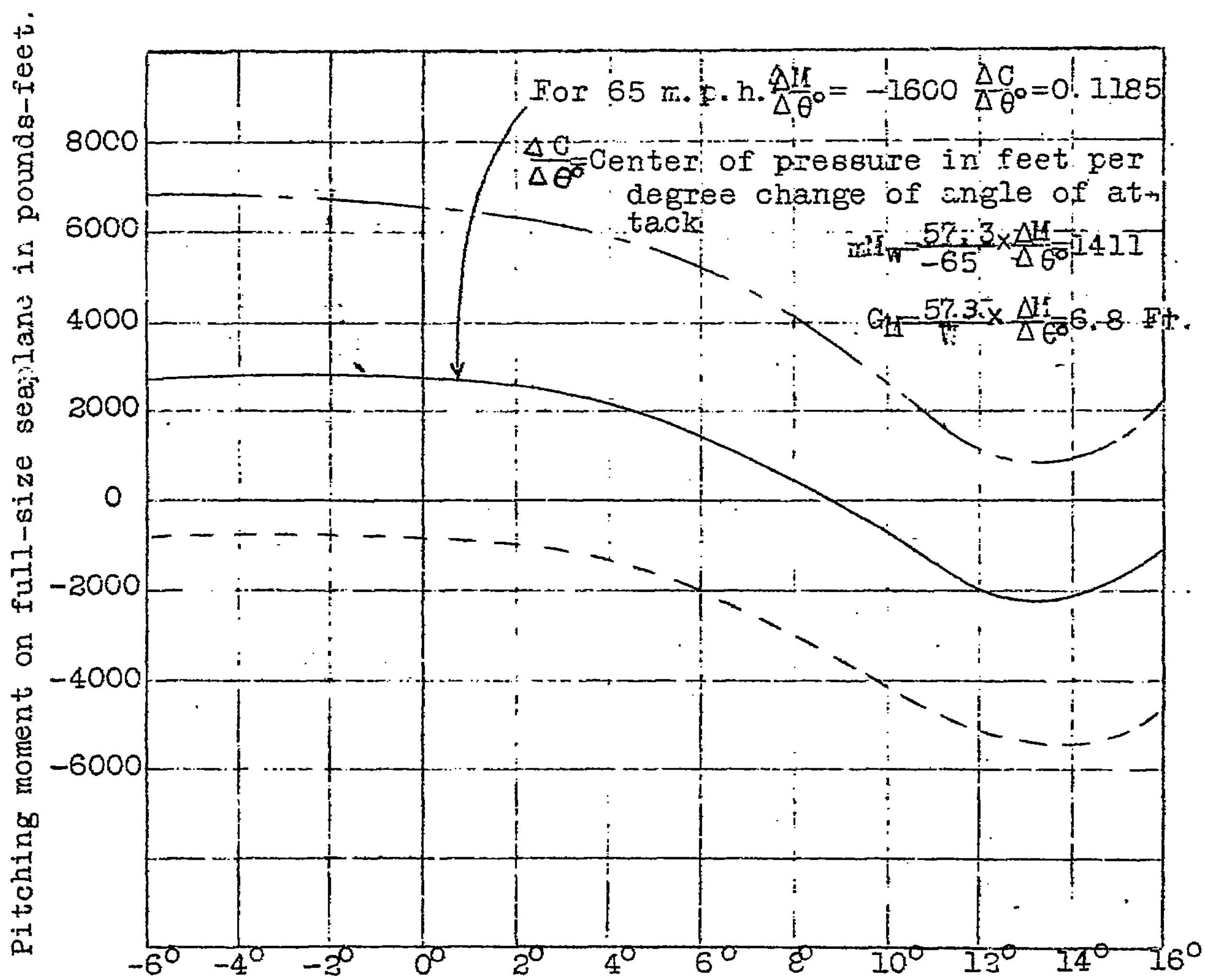


Fig. 2. Apparatus for measuring rolling moments.

W=Weight in pounds for full-size seaplane.
-U=Velocity in m.p.h. of seaplane.
θ=Inclination of longitudinal axis to the horizontal.
For reference axis for pitching moments see Fig. 13.
mM_W=Variation of pitching moment due to change of normal velocity for full-size seaplane.
G_M="Metacentric height" for full-size seaplane.



Angle of attack of chord of upper wing.

Fig. 3. Pitching moment about an assumed axis at 40 m.p.h.

———— – ———— Elevators 10° up.
———————— " 0°
– – – – – " 10° down.

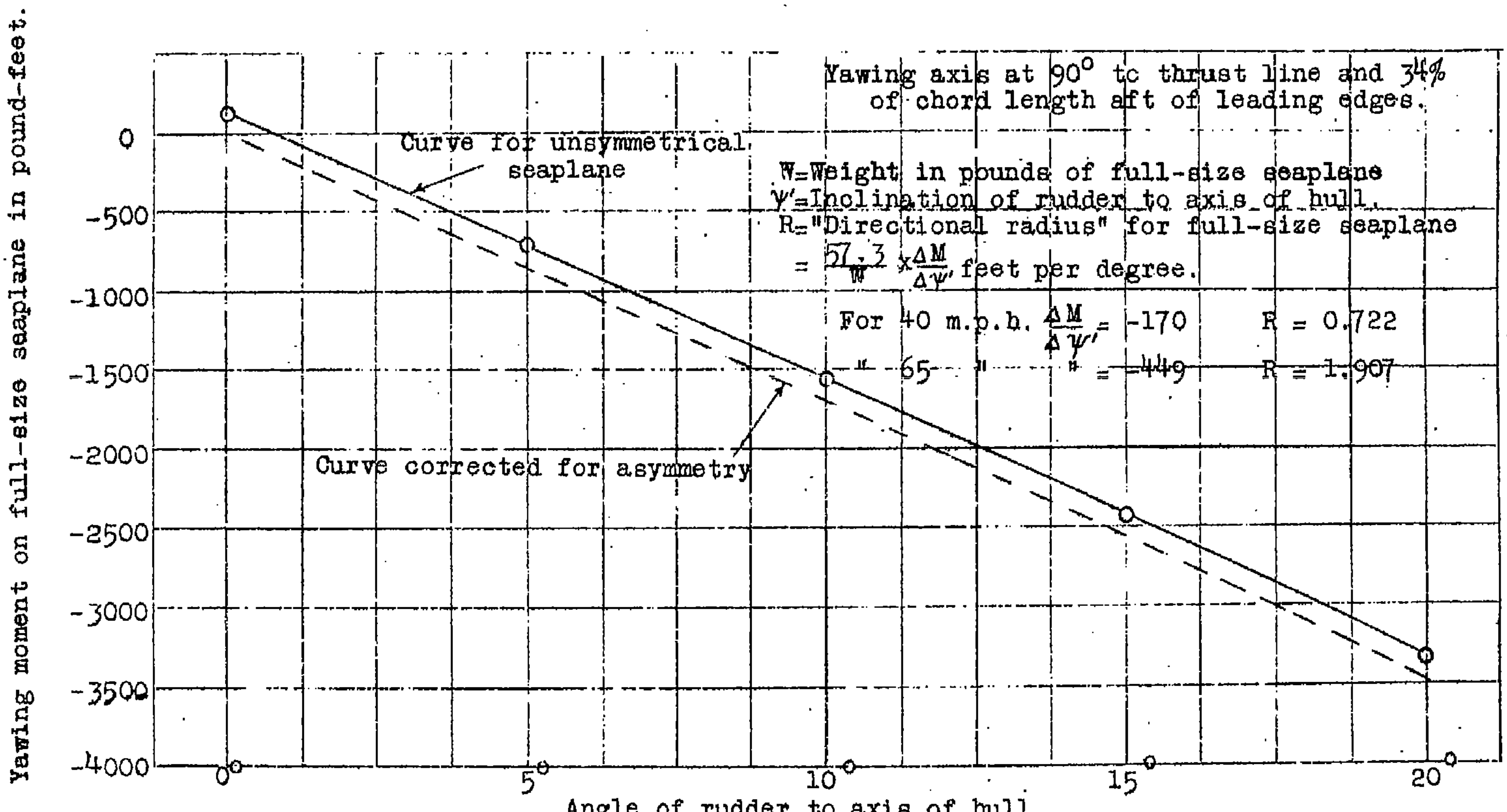


Fig. 4. Yawing moment for various rudder angles. Axis of hull parallel to wind. Wind speed 40 m.p.h.

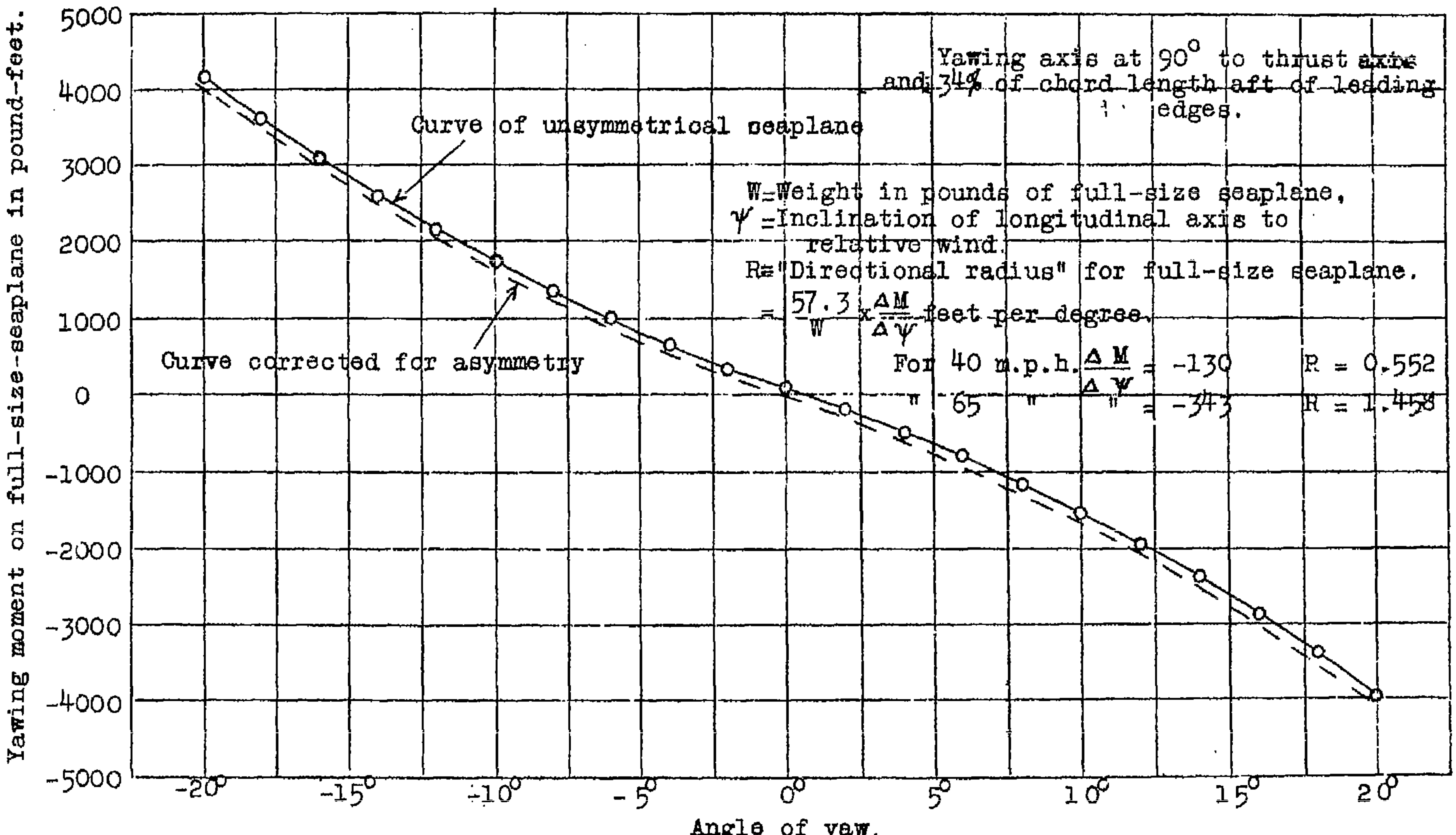


Fig. 5. Yawing moments with hull yawed and rudder neutral to hull. Wind speed 40 m.p.h.

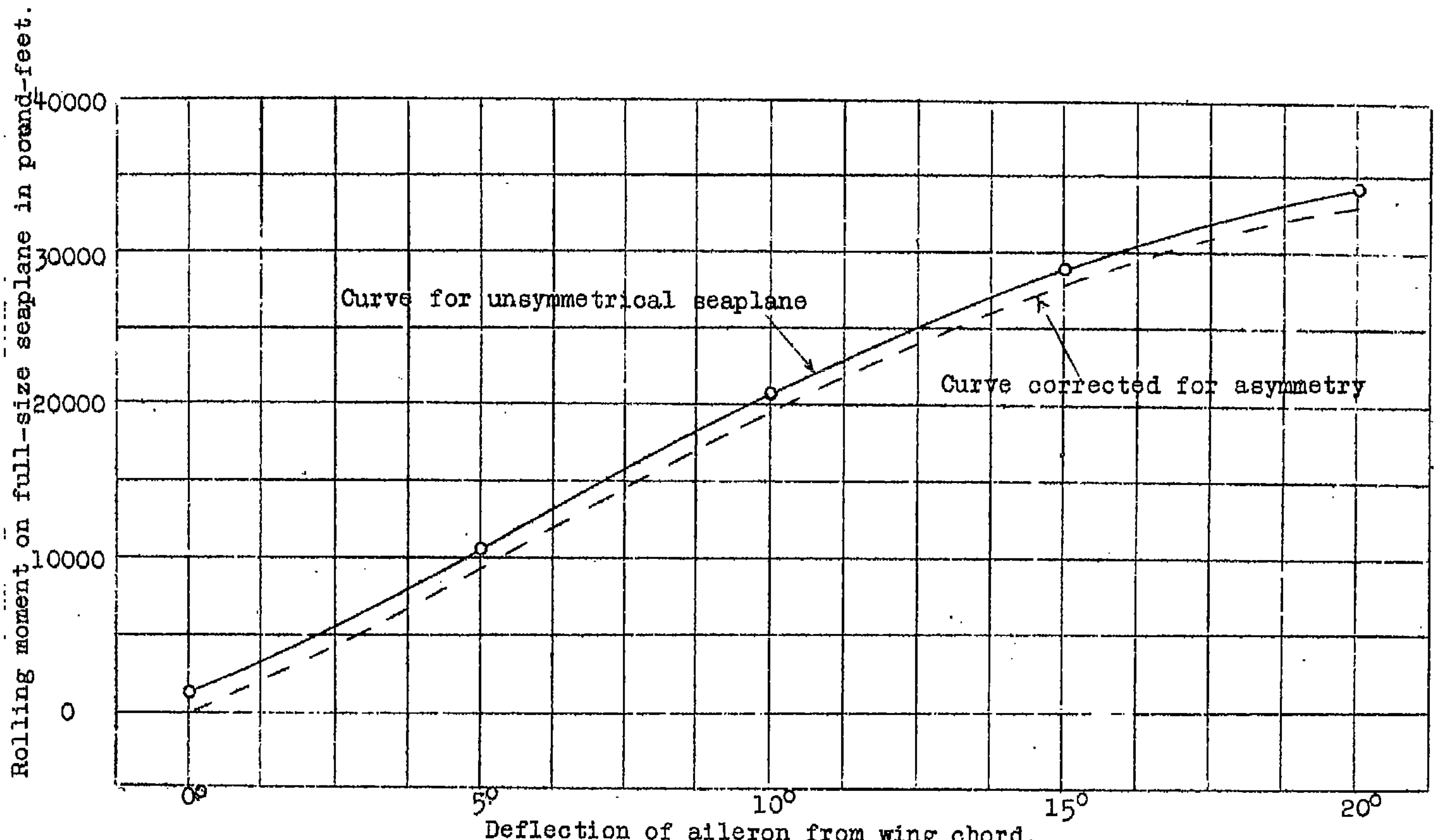


Fig. 6. Rolling moment at various positions of ailerons. Axis of hull parallel to wind.
Wind speed 40 m.p.h.

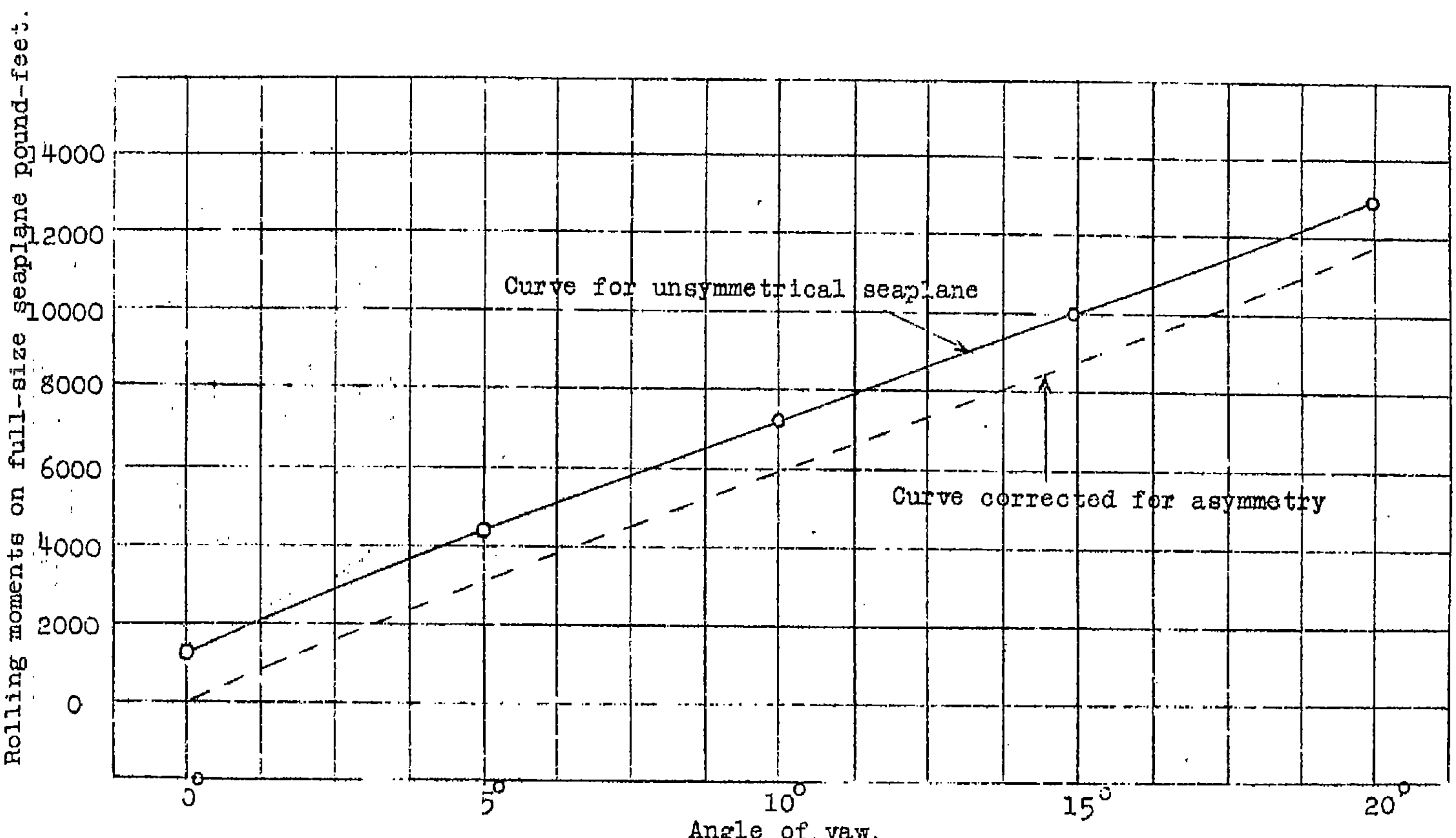


Fig. 7. Rolling moment at various angles of yaw with aileron neutral. Wind speed 40 m.p.h.

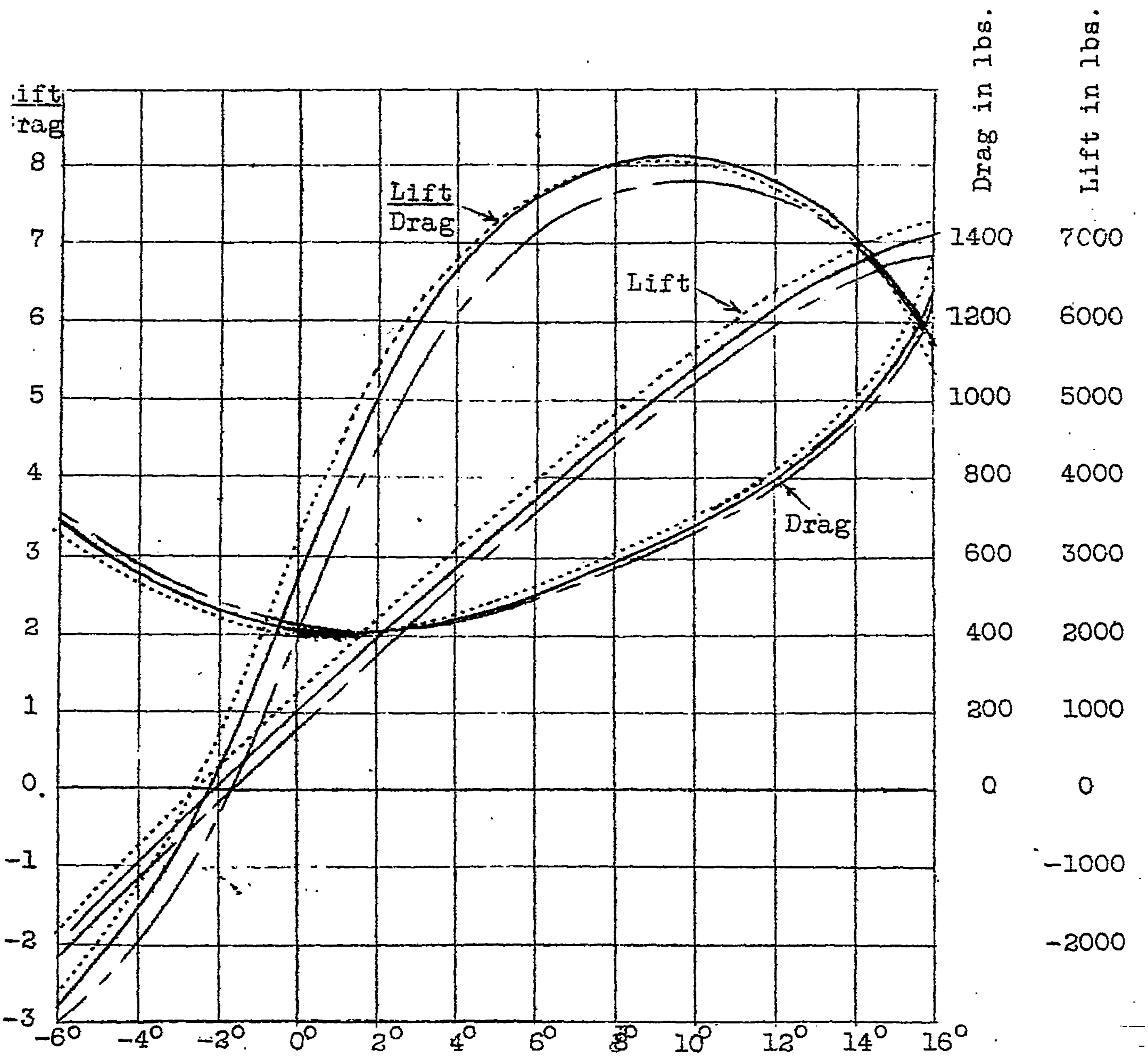


Fig. 8. Lift, drag, and $\frac{\text{lift}}{\text{drag}}$ at 40 m.p.h. on full-size seaplane.

————————	Experiment	1	elevators	at	0°
——— — ———	"	2	"	"	10° up.
....	"	3	"	"	10° down.

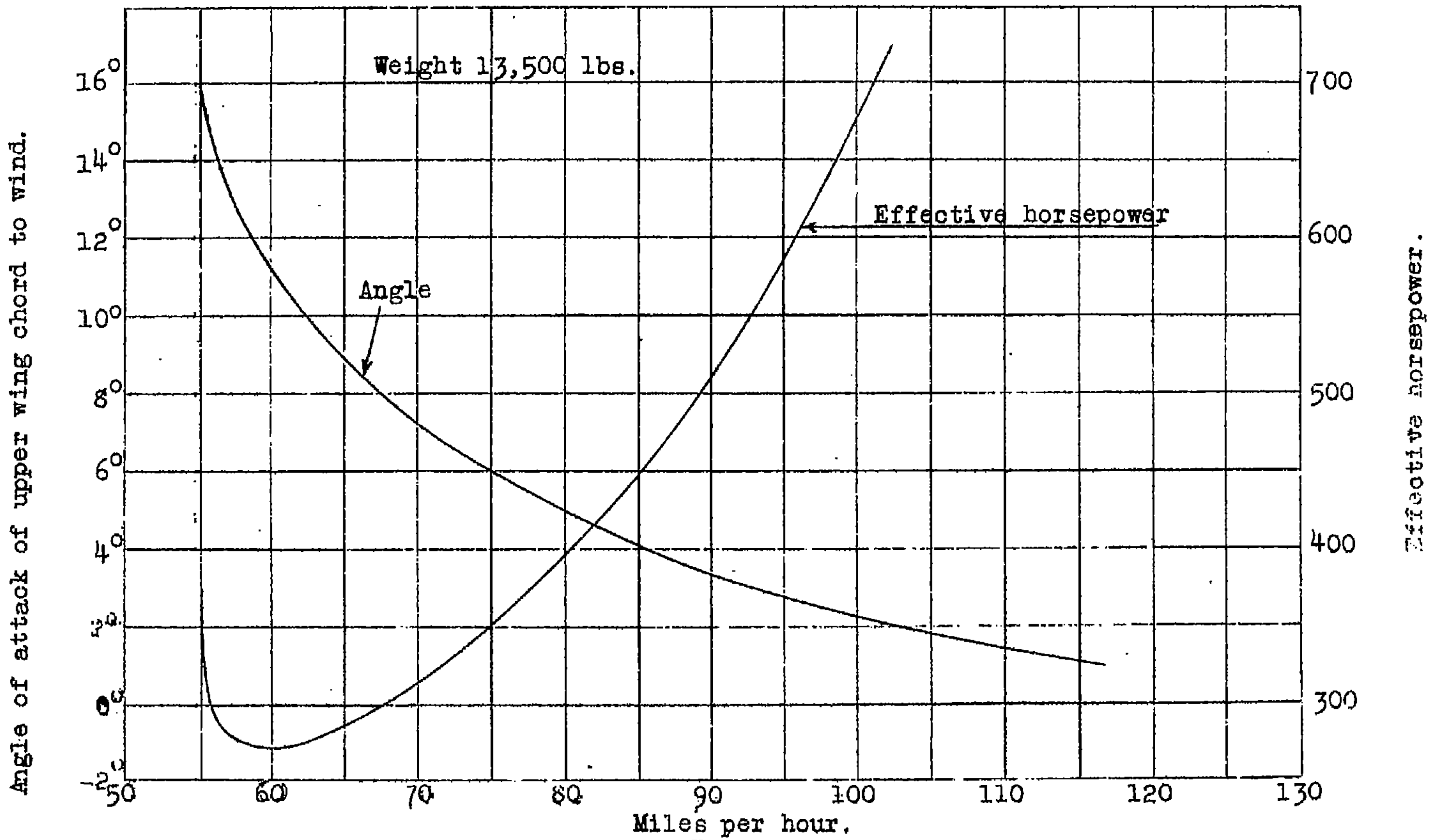


Fig. 9. Effective horsepower and angle Elevators neutral.

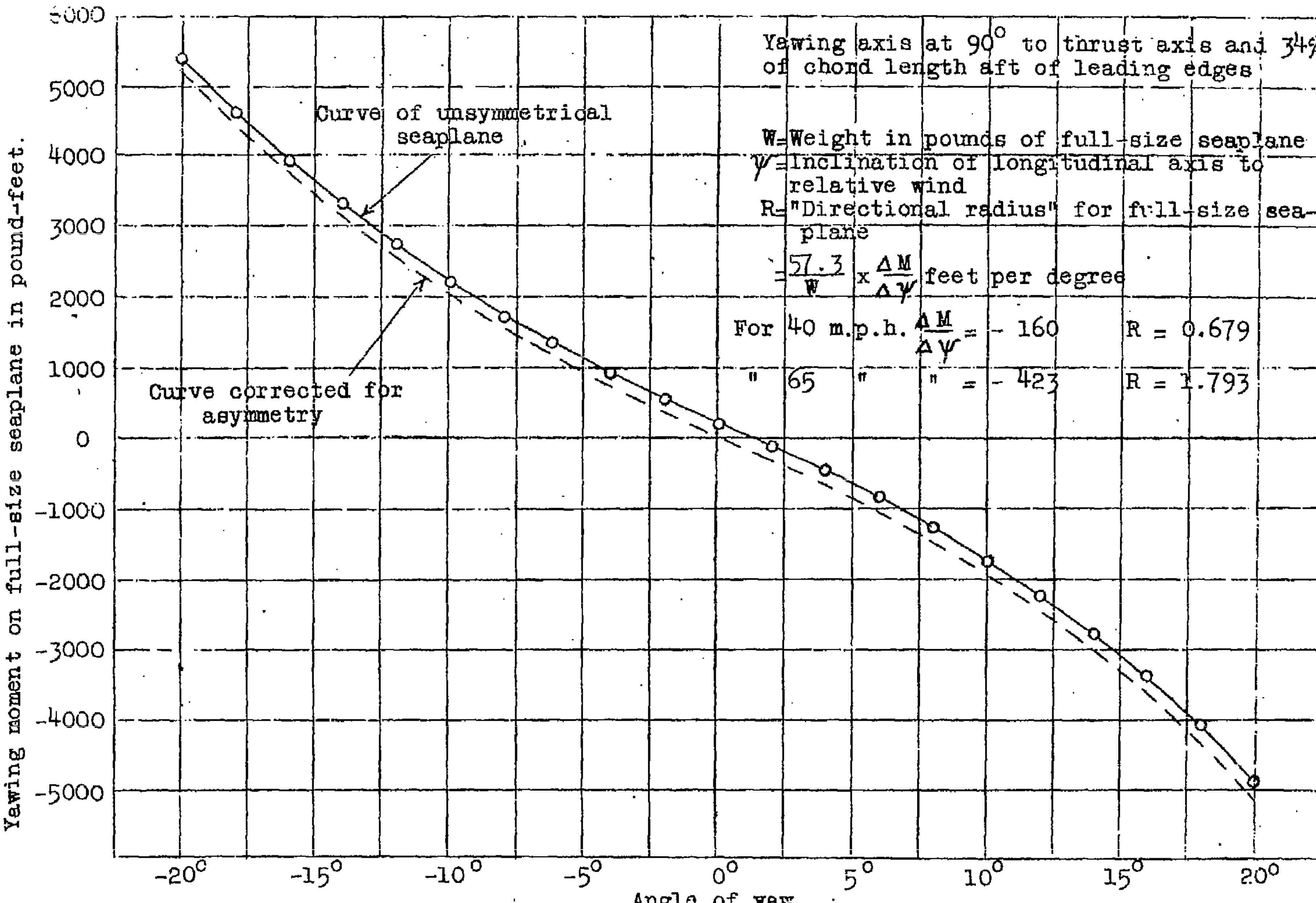


Fig.10. Yawing moments with hull yawed and rudder neutral to hull. Revised fin.
Wind speed 40 m.p.h.

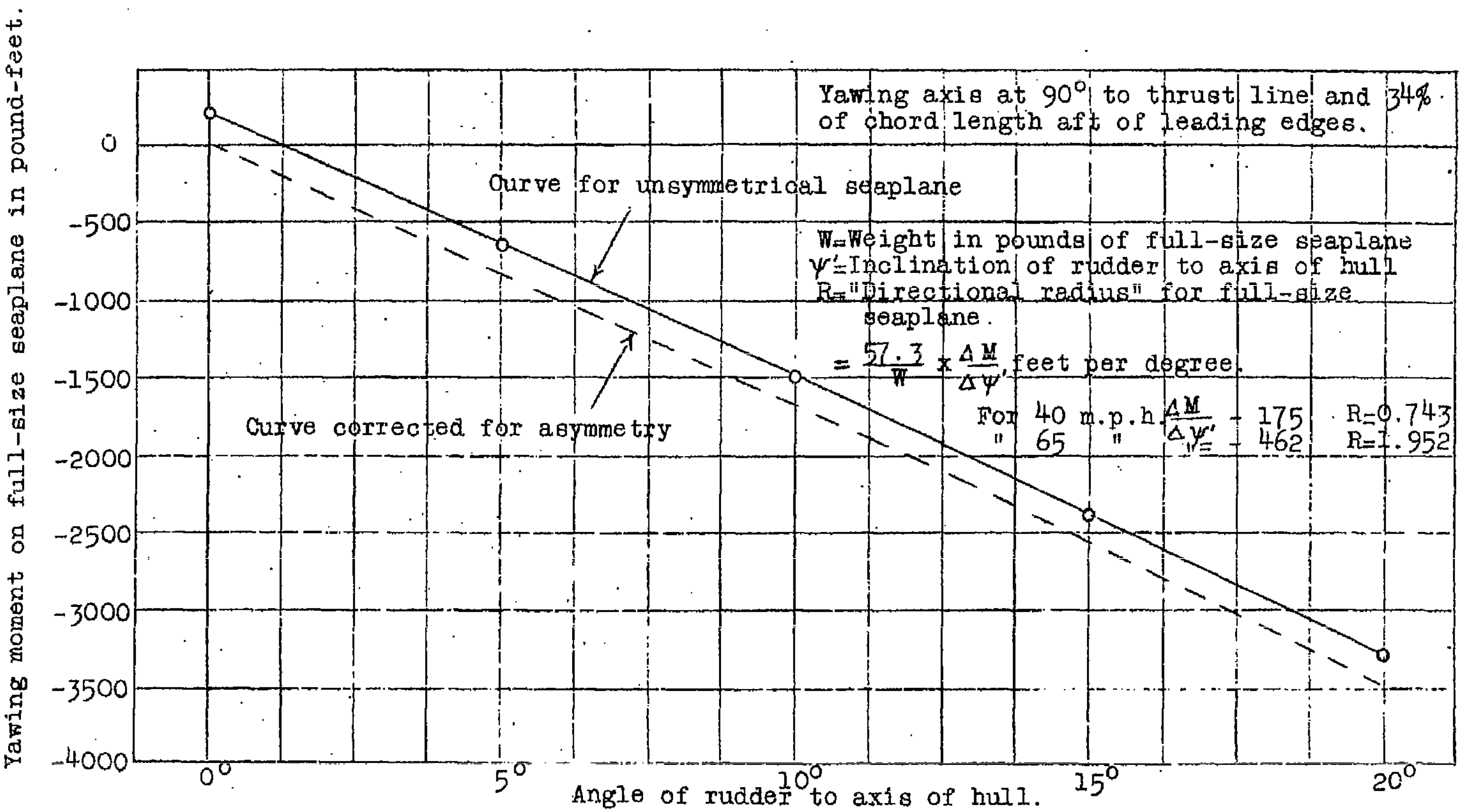


Fig.11. Yawing moment for various rudder angles with revised fin. Axis of hull parallel to wind. Wind speed 40 m.p.h.

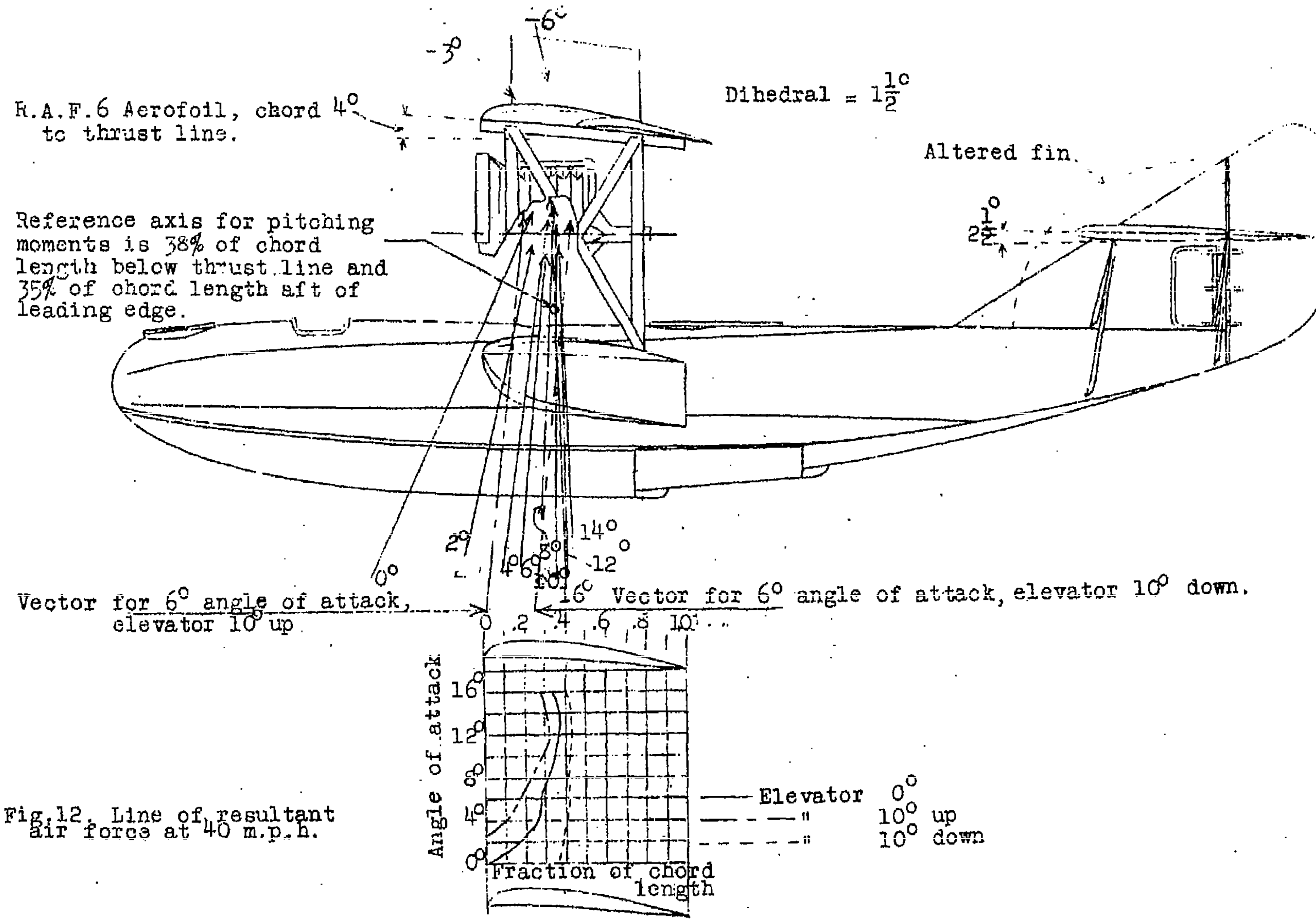


Fig.12. Line of resultant air force at 40 m.p.h.

Center of pressure travel along horizontal plane through C.G. for fixed pitch axis shown.

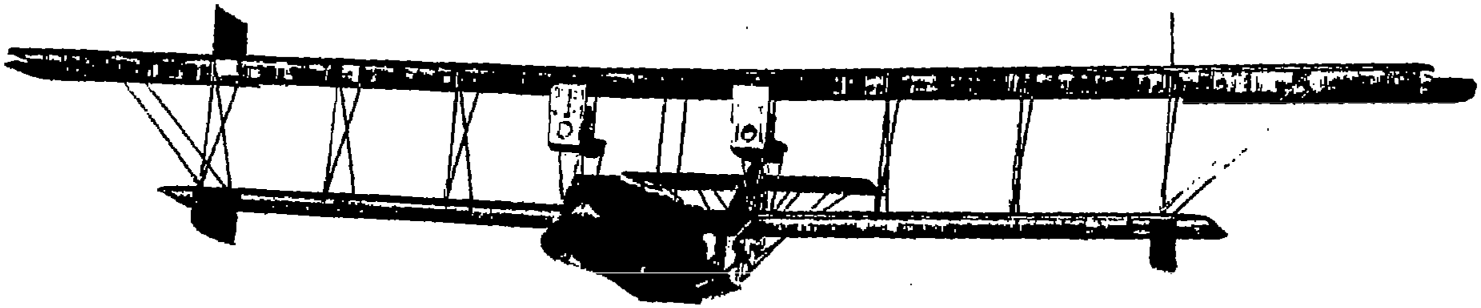


Fig.13

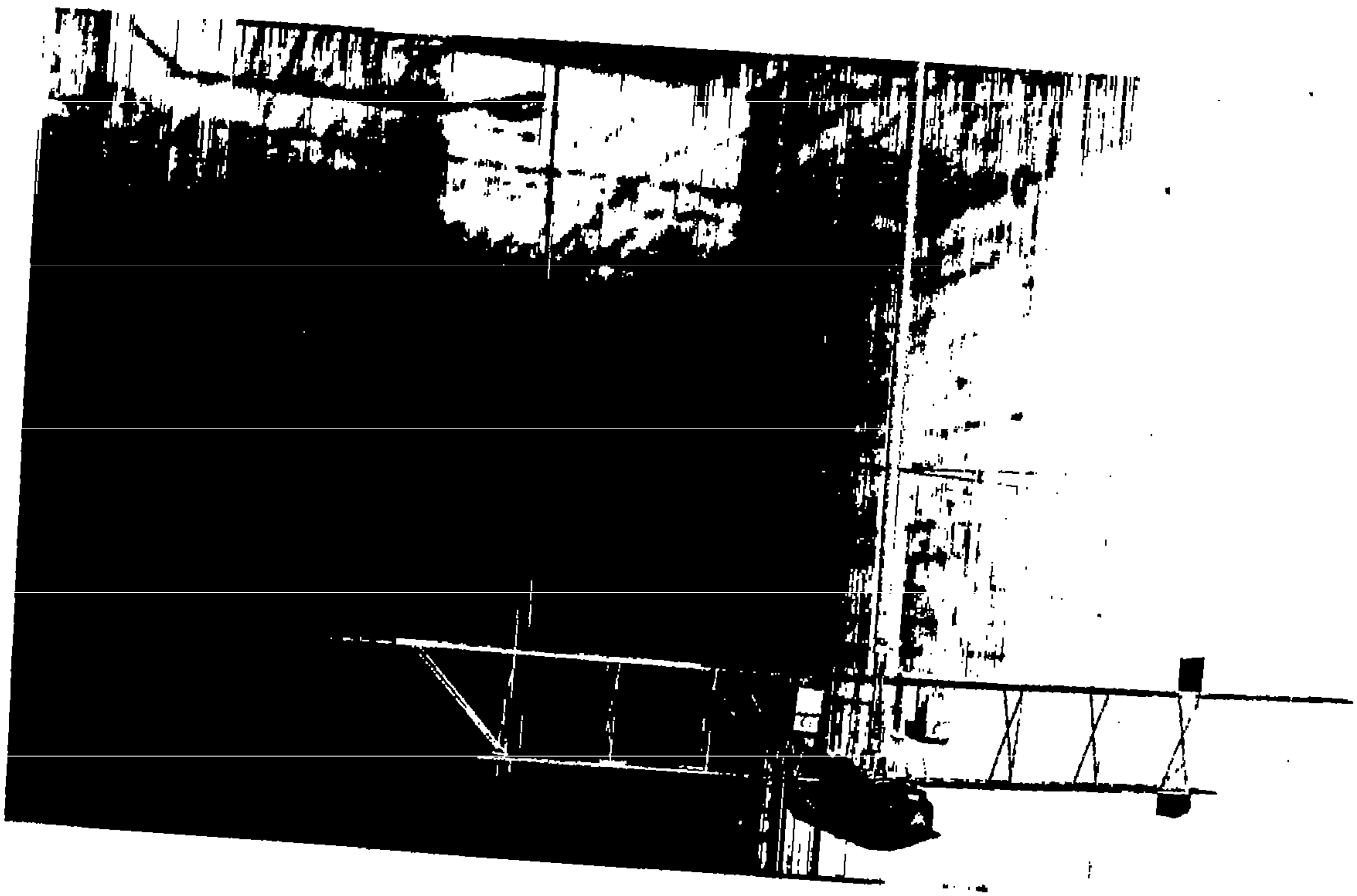


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Fig.14

APPENDIX.

Comments on the Preceding Tests.

By Max M. Munk.

The results of the preceding tests are very suitable for checking a formula or rather the existing method for the calculation of the moment produced by the displacement of, for instance, the elevator. This formula would be:

$$(1) \qquad \frac{L}{\epsilon\, S\, q} + \frac{L}{\epsilon\, S\, q} \times \frac{S}{b^2} \quad \frac{57.3}{\pi} = K$$

wherein

- L the lift produced by a displacement
- ϵ angle of displacement
- S the area of the elevator
- b the greatest span of the elevator or tail plane
- q the dynamical pressure of the speed as given by the Pitot tube.
- K a coefficient, which is not variable to a great degree, is about 1.3 for the usual ratio of the elevator and tail plane area.

The meaning of the formula is as follows: The first term is the lift per unit of elevator area, dynamical pressure and displacement. 57.3 L/b q is the decrease of the induced angle of attack in degrees which multiplied by 0.1 S q gives the corresponding lift; while the second term gives this lift per unit of the area, dynamic pressure and displacement. The left side thus represents the entire result of the displacement, the second term is the part neutralized subsequently by the aerodynamical induction.

In order to check up this formula I proceed now to calculate the factor K from the results of the preceding tests. I divide the moments obtained from respective arms, by the dynamic pressure, the area and the displacement. To this I add the change of the induced angle of attack multiplied by 0.1. The sum is the coefficient K. I begin with the elevator and refer to the full-sized seaplane.

A 20° displacement of the elevator produced a pitching moment of 7250 ft. lbs., the arm being 16.2 ft., the elevator area 55.3 sq.ft., and the dynamical pressure 4.1 lbs.sq.ft. The product of area, arm and dynamic pressure is 3670 lbs. ft. The increase of the moment per 1° is 362 ft. lbs., hence the increase of the corresponding lift coefficient with reference to the elevator area is

$$362/3670 = 0.099$$

(which is the first term of equation 1)

The span of the elevator is 19.5 ft., hence the area ratio

$$\text{area}/\text{span}^2 = 55.3/19.5^2 = 0.121$$

(giving the second term of the equation)

and the induced angle of attack for the lift coefficient 0.099 is

$$0.099 \cdot 0.121 \cdot 57.3/\pi = 0.22^\circ$$

an angle which corresponds to a lift coefficient ten times as as small, that is, 0.022. Hence the real effect is so much greater, that is

$$0.099 + 0.022 = 0.121$$

and the theory supposes this coefficient to be constant for each ratio elevator/tail-plane and to be in the neighborhood of the obtained value for the present ratio.

The rolling moment, as produced by the displacement of the ailerons, can be treated similarly. The product of area, arm, and dynamic pressure is now 20,400 lbs./ft. for the full-sized seaplane and the produced moment per 1° displacement is 2,000 lbs. ft., therefore:

$$C_L = 0.1 \text{ per } 1^\circ$$

The ratio of the aileron chord to the wing chord is about the same as with the elevator and the effect of the induction ought to increase this coefficient to about 0.12 as before. This effect however cannot be calculated as easily as before, but on the contrary could be determined by model tests similar to the present one. In this particular case the space between the aileron and the wing was particularly great, thus decreasing the aileron effect, and that is the reason why this test is not well fitted for this calculation. It can be seen, however, that the obtained value is not very far from the expected value.

The yawing moment is produced by a rudder area of 33.5 sq.ft. and the product of this area by the arm and the dynamic pressure is 2220 lbs. ft. The moment corresponding to 1° displacement of the rudder is 160 lbs. ft., giving the first term a value of

$$C_L \doteq 0.072$$

The vertical span of the tail unit can be considered to be about

10 ft., giving an area ratio

$$33.5/10 = 0.335.$$

The induced lift coefficient for 0.072 is now

$$57.3 \cdot 0.1 \cdot 0.072 \cdot 0.335/\pi = 0.054$$

increasing the apparent effect to the real effect

$$0.072 + 0.054 = 0.126$$

This is approximately the same value again as with the elevator.

The yawing moment produced by a yawing angle is a function of the shape of the entire seaplane and cannot be calculated as before. This also holds true for the increase of the moment as produced by the increase of the tail plane area, as the effective angle of attack is unknown. In the present case the increase is the same as if the effective angle of attack is only 38% of the yawing angle. It is known however from experience that the physical law between an increase of tail plane and the produced effect is very irregular and an increase of the area can even result in a decrease of the stability. The phenomenon is much dominated by the viscosity of the air, and such model tests which are not at full scale with respect to viscosity must be regarded as doubtful.

The effect of the displacement of the controlling surfaces as observed by this model test well agrees with the computation and hence these tests augment the confidence in these modern methods of aerodynamic computation.